International Journal of Signal Processing Systems Vol. 1, No. 1 June 2013

Image Registration with Hyperspectral Data Based on Fourier-Mellin Transform

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***Abstract*—Hyperspectral imagery is playing more and more important role in many fields such as geology, agriculture, environment, military, atmosphere and so on. We need to register Hyperspectral imagery so that we can build coherent image cubes and get coherent spectrum of pixels. Our concern in this paper is the Fourier-Mellin Transform (FMT) for image registration process and its related techniques for real hyperspectral data. FMT can recover translation, rotation. It is computationally efficient. Techniques such as filter, window and downscale for improving precision in the registration process are taken/put forward and discussed. With highpass emphasis filter and downscale for registration of real hyperspectral data can get a right or better result in some situation.**

***Index Terms*—image registration, hyperspectral, Fourier-Mellin transform, log-polar transform, remote sensing**

I. INTRODUCTION

Image registration is the process of overlaying two or more images of the same scene taken at different times, from different viewpoints, and/or by different sensors [1]. Many image registration methods were introduced in [1]–[3].

Hyperspectral imagery consists of dozens to hundreds of contiguous wavebands, which means we can get each pixel's coherent spectrum. We can identify the material of pixel by the correspondence coherent spectrum. For applications of the advantages of hyperspectral data, we should register hyperspectral images at first. Approaches are introduced for registration of remote sensing [4], [5].

Fourier-Mellin Transform (FMT) can recover scaling, rotation, and translation [6]. Furthermore, the method shows excellent robustness against random noise and brightness [7]. It is very popular for remote sensing imagery registration. In this paper, we use and discuss the FMT algorithm to register hyperspectral imagery acquired from mobile platform. Some properties of the FMT were discussed and techniques for improving precision in the registration process were taken/put forward.

This paper is organized in the following way. In Section II, we describe the idea of FMT to image registration. Section Ⅲ, drawbacks of the FMT were discussed and some techniques for improving precision in the registration process were talked about. Section Ⅳ demonstrates implementation and application of FMT in hyperspectral data. Discussion about the experiment is shown in section Ⅴ. Finally, conclusion is given in section Ⅵ.

II. THEORY

In this section, we present the theory of FMT for image registration.

A. Translation Property of the Fourier Transform

Let f_1 and f_2 are the two images that differ only by a displacement (x_0, y_0), i.e.,

$$f_2(x,y) = f_1(x-x_0, y-y_0) \tag{1}$$

Their corresponding Fourier transforms F_1 and F_2 will be related by

$$F_2(u,v) = F_1(u,v)e^{-j(ux_0+vy_0)} \tag{2}$$

The cross power spectrum of the two images is defined as

$$\frac{F_1(u,v)F_2^*(u,v)}{|F_1(u,v)F_2^*(u,v)|} = e^{j(ux_0+vy_0)} \tag{3}$$

where F^* is the complex conjugate of F.

The inverse Fourier transform of (3) will produce an impulse function and the location (x_0, y_0) is the peak. This means if there is only translation between two images we can use the so called phase correlation (PC) method to register the two images.

B. Fourier-Mellin Ttransform

Consider two images f_1 and f_2, f_2 is a translated, rotated and scaled replica of f_1 with translation (x_0, y_0), rotation θ_0 (anticlockwise) and scale s ,then

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Manuscript received May 3, 2013; revised August 1, 2013

doi: 10.12720/ijsps.1.1.107-110

$$f_2(x,y) = f_1[s(x\cos\theta_0 + y\sin\theta_0) - x_0,\\ s(-x\sin\theta_0 + y\cos\theta_0) - y_0] \quad (4)$$

The magnitude of their corresponding Fourier transforms F_1 and F_2 are related by

$$|F_2(u,v)| = s^{-2}\,|F_1[s^{-1}(u\cos\theta_0 + v\sin\theta_0),\\ s^{-1}(-u\sin\theta_0 + v\cos\theta_0)]| \quad (5)$$

Equation (5) shows the magnitude of Fourier transforms are only related with rotation θ_0 and scale s. For (5), change the coordinate system from Cartesian (u,v) to log-polar coordinate system (λ,θ), then

$$|F_2(\lambda,\theta)| = s^{-2}\,|F_1(\lambda-\lambda_0, \theta-\theta_0)| \quad (6)$$

where, $\lambda = \log\left(\sqrt{u^2+v^2}\right)$, $\lambda_0 = \log s$ and $\theta = \arctan\left(\frac{v}{u}\right)$.

From (6) we find it is similar with (1). Obviously, λ_0 and θ_0 can be computed in log-polar coordinate system using the PC method mentioned in section Ⅱ part A**,** so that rotation θ_0 and scale s will be find easily. So we can register images by two steps, first compute rotation θ_0 and scale s and then decide translation parameter (x_0, y_0).

III. DRAWBACKS AND IMPROVEMENT

Before using the FMT algorithm to image registration, some issues are discussed in this section.

Stone and Mcguirre [7] discussed the fact that the discrete Fourier transform does not commute with the rotation of sampled-images, whereas in the continuous domain the corresponding operations do commute. We usually use a window and filter to repress or remove this artifact [7]-[9]. Chen, Defrise and Deconinck [6] use a Hanning window and Stone and Mcguirre [7] use a Blackman window to remove spurious high frequencies in the spectral leakage and Reddy and Chatterji [10] use a highpass emphasis filter to reduce this artifact.

However, when we use the FMT algorithm in real hyperspectral data we found the FMT algorithm cannot register some images. If downscale the image in a proper size, this problem can be settled. After parameter is computed in downscale size, we should adjust the parameters to original image size carefully. More details will be discussed in section Ⅴ.

By the way, since Fourier spectrum is conjugate symmetric for real sequence, the angle there is a 180° ambiguity. We rotate image f_2 by $-\theta_0$ and $-(180^\circ + \theta_0)$ then compute the translation respectively. If the value of the peak of the IFFT of the cross power spectrum is larger the angle is θ_0, otherwise the angle is $(180^\circ + \theta_0)$. The process is shown below (Fig. 1).

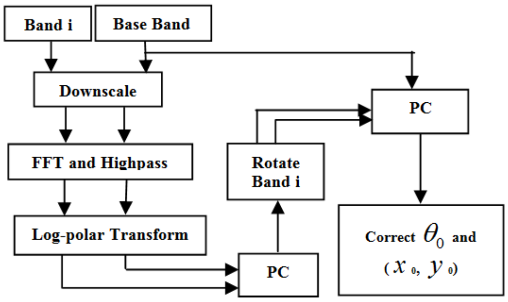


Figure 1. Flow diagram of the registration.

IV. IMPLEMENTATION AND APPLICATION

The experiment conducted are based on 25 bands hyperspectral data which acquired from an mobile hyperspectral imaging platform, each band is about 7nm width, pixel's space resolution is about 1.5m*1.5m. In the mobile mode, the system may produces large registration offsets between band because the platform are moving during a mission, bring few rotation cause from vibration of the system, and scale factor are negligible because the altitude of the sensor is fixed [11]. To co-register the 25 bands hyperspectral images, we choose the middle band (band 13) as the base band with the ground target centered in the image.

Two issues need to be mentioned with the experiment. One issue is the highpass emphasis filter, we choose (7), the same as [10]

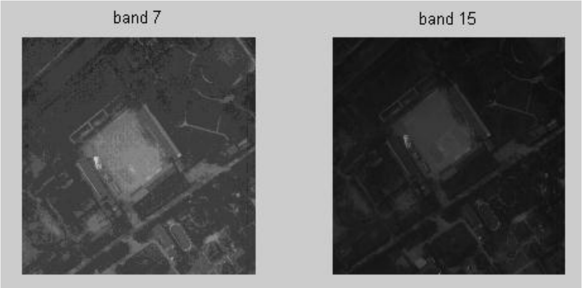
$$H(u,v) = (1.0 - X(u,v)) * (2.0 - X(u,v)) \quad (7)$$

where $X(u,v) = [\cos(\pi u) * \cos(\pi v)]$ and $-0.5 \le u,v \le 0.5$.

The other issue is the angle θ_0, we get it by the formula as following

$$\theta_0 = \frac{360^\circ}{SizeY} * (y-1) \quad (8)$$

where (x,y) is the location of the peak of the inverse Fourier transform of the cross power spectrum. SizeY presents the number of the column. So the angle is discrete.



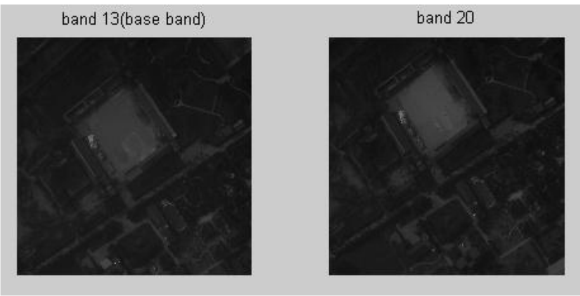


Figure 2. Original images from aerial hyperspectral data.

Fig. 2 shows a representative example of the hyperspectral data acquired from the mobile platform. If original size cannot achieve the true result, we select a proper downscale size to get correct registration result and rescale the parameter to original size.

The results are summarized in Table I. Downscale with 0.5 means each dimension rescale to 50% of original. We downscale the images by bicubic interpolation. The unit of rotation is degree and translation is pixel. The translation has already been rescaled to original size.

TABLE I. THE RESULT OF IMAGE REGISTRATION

	Band 7	Band 13	Band 15	Band 20
downscale	0.5	1	1	0.5
rotation	0.71	0	0	358.93
translation	-172,-16	0,0	56,8	206,22
Peak value	0.0370	1	0.0512	0.0748

Only if we find the result of 25 images, can we get all images co-registed. We first find transform parameter of each image with base band (band 13). Then we recover the rotation of each image. At last get the maximum and minimum of the translation of all images, so that we can cut all images into the same size easily. Registration results are shown in Fig. 3 (only all 25 bands corresponding part are reserved).

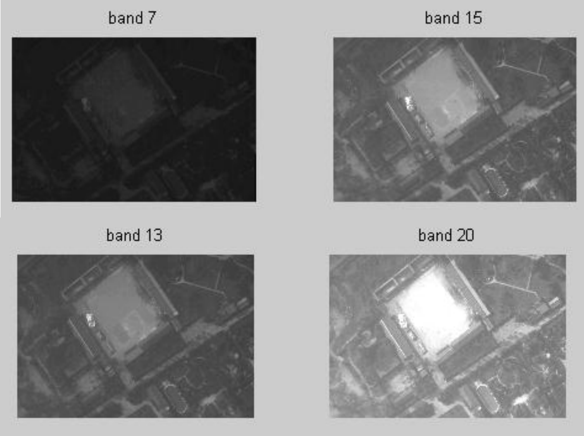


Figure 3. Registered images of Figure 2.

V. DISCUSSION

From the experiment, we find that window the images do make the peak more sharp and the peak value greater. But we found this may not get the right result unless a proper downscale size is taken (Fig. 4 and Fig. 5). Fig. 4 shows a worse result while Fig. 5 shows better result.

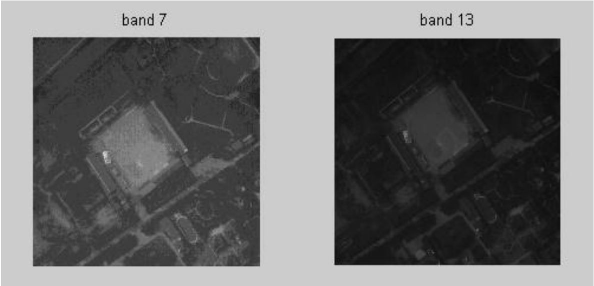


Figure 4. Registered images with no downscale with FMT.

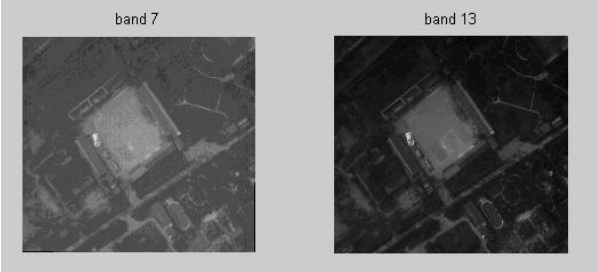


Figure 5. Registered images with 50% downscale with FMT.

In fact, Fig. 5 also has registration error such as interpolation error caused by downscale, upscale, coordinate transform and recover rotation, also noncommutativity of rotation and discrete Fourier transform. By the way, the translation may be sub-pixel, this paper can only find integral pixel translation. The rotation θ_0 we find is discrete, it’s another source of registration error.

Fortunately, the imagery has high space resolution, the precision of the method in this paper can satisfy the application basically.

Why downscale is needed here? It may because of the property of imagery. We may interpret this by the theory of multiresolution analysis (MRA). Since the two images are acquired by different bands and have different information of same scene. The proper downscale size means lower space resolution and more similar between the two images while the original size makes the details of the two more different.

If the quality is better, downscale may became unnecessary. The effect of downscale is similar as Hanning or Blackman window. The mainly difference is downscale remove more spurious high frequencies in the spectral leakage created by the image boundary.

VI. CONCLUSION

Fourier-Mellin Transform (FMT) can recover scaling, rotation, and translation and it is robust to brightness and noise. This approach is very attractive because it is computationally efficient. It is quite popular for image registration for hyperspectral imagery. We use highpass emphasis filter and put forward downscale for registration of real hyperspectral data. From the experiment we confirm that downscale is necessary in some situation.

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